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Automated control system generation out of the virtual machine

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Abstract

To drastically reduce the commissioning time of a machine tool innovative companies rely more and more on the possibilities of virtual commissioning - commissioning of real controls on virtual machines and plants in order to improve the accuracy and robustness of acting programs. These virtual machines and plants require data defining their behavior and appearance.

The mechanical engineering, which is focused on machine modules, uses engineering tools for configuration and parameterization of the needed control systems. These software tools have knowledge of the cross-relationships and dependencies of the individual modules to each other and derive the required data for the control systems (CNC, PLC, …) but also, e.g. the needed documents from a central database. It is desired to generate the required virtual machines and plants automatically and use them for the test of the control systems.

In the research project "CassaMobile" a module is understood as a self-sufficient unit, which includes all mechanical and electrical components to fulfil the intended function and either has its own control system or is controlled by a central control system. The difference from engineering by commissioning lists is, that the control system receives a list of all available modules through a query of the physical machine and that the modules are explaining themselves to the control system and not by a central data base. This is made possible by a module-specific configuration memory such as the CIMory (Configuration and Information Memory). An automatic configuration of the control system on the basis of CIMory data has already been presented.

This approach does not require a central data base out of which a virtual machine could be generated. However, the commissioning of the control system can be done only after the construction of the actual machine. To overcome this disadvantage, for "CassaMobile" a virtual equivalent was developed: by using the commissioning list, a virtual machine is generated out of virtual modules which is used for virtual commissioning of the control system. The virtual modules can be detected by the control system and have the possibility to explain themselves to the control system like their physical equivalents. The CIMory gets a virtual expression.

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1. Introduction

Modern engineering has developed modular concepts and enables it to provide economic production for various production tasks. By using this modular concept, many companies understand the term "module" not only limited to the hardware, but use them for mechatronic units. According to [1] the choice of system boundaries determines the complexity of the module interface. In this context, a mechatronic component by definition is a sub-system [2], which has as few external interfaces as possible. This also means that mechatronic components are limited to a single or a few equal functions [3], e.g. a spindle or a drilling unit, so that the mechatronic component forms a self-contained, autonomous unit. Accordingly, modern machine tool companies are able to build up a module pool, out of which a basic machine can be extended by mechatronic components to perform various functions.

In the literature, a "mechatronic component" or a "mechatronic module" is defined as an autonomous unit consisting of mechanical, electrical and control units [1]. In recent years, this definition has become softer. More and more, self-contained units are already considered "mechatronic" when they consist of mechanical and electrical systems, even if they have to be connected to a central control system to perform their function, so they do not own the needed control system function. This definition will be chosen for this paper.

If this modularization is driven further, a mechatronic component could have dependencies to other mechatronic components and could require them to fulfill its function. For example, the mechatronic component "spindle" could contain the component "pneumatic tool changer". This requires the mechatronic component "compressor". If the overall machine tool now contains more mechatronic units that require the mechatronic component "compressor", either another component "compressor" or a stronger component "compressor" may be required. Commissioning tools know about this relationship and consider it by commissioning a machine tool.

Within the CassaMobile project [4], a mobile, flexible, modular, small-footprint manufacturing system in an ISO-container that can be easily configured for different products and processes by adding or removing production modules to or from the container. Doing so, a perfectly matched production system can be provided for every use case. (see Figure 1)

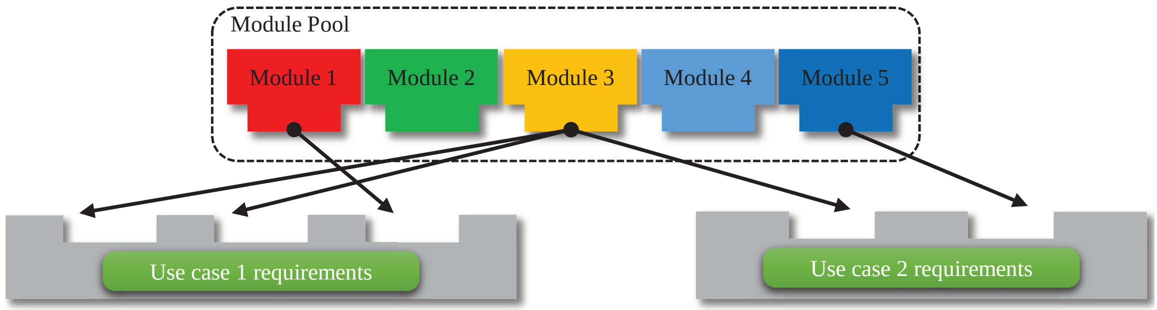

Figure 1: Concept of the Modular Production System (MPS) combining modules to fit the use case requirements [5]

According to the current state of technology, the research project "CassaMobile" defines the production units as completed mechatronic units, which are in turn composed of mechatronic components. They contain all mechanical and electrical components in order to fulfill its intended function. The manufacturing units themselves do not need their own control system, but can be controlled by a central control system (CCS). The control configuration and parameterization is automatically generated from information that is provided by memories, which are part of each production unit and its mechatronic components. The memories are known as "CIMory" (Configuration and Information Memory). They are production unit specific.

Considering a real mechatronic unit, from the hardware perspective, it owns a communication interface in the form of a fieldbus, a power supply and a supply of operating materials [1]. From the controller perspective, however, only the communication interface is "visible", which is available as memory area in the shared memory (SHM) of the fieldbus driver. The size of the memory area is defined by the number of inputs and outputs, as well as their datatype (see Figure 2).

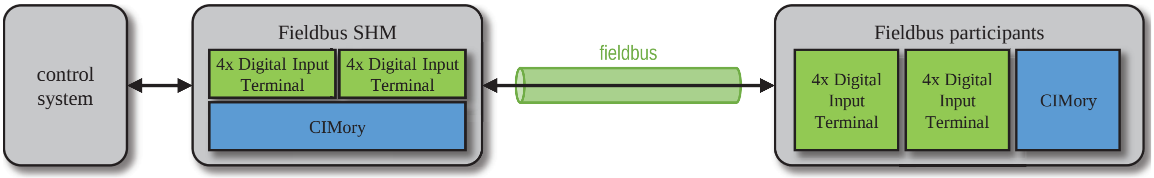

Figure 2: Communication route from control system to fieldbus terminal

Relationships between different production units, which are needed for the realization of the control system are described by data stored in the CIMory. The configuration and parametrization of the control system can automatically be done after connecting the production unit with it [3][5]. Already at the beginning of the research project "CassaMobile" it was recognized that planning the project according to the classic and established "workflow" of the machinery industry (see Figure 3), the project targets cannot be achieved within time.

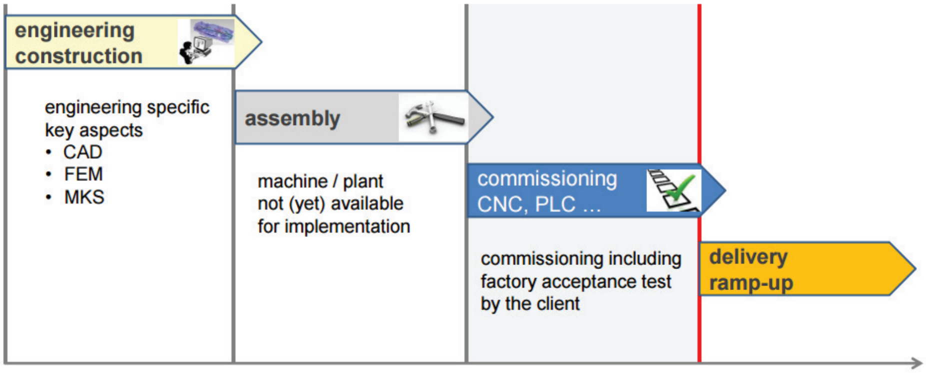

Figure 3: Classic development process of a machine tool [6]

Due to the tight project schedule and the planned extensive software development, in the research project "CassaMobile" it was not possible to wait for completion of the production units until the control system ramp up can be done. Therefore, an alternative solution was sought, which allows all partners involved in software projects to begin work as early as possible. This solution has been found in the virtual commissioning.

2. Virtual Commissioning

In recent years, software tools have been developed which allow manufacturers of machine tools and production systems to commission their software based on a virtual image of their product. [7] Advantage of such a solution is not only that it is possible to parallelize the processes of the development process of a machine tool as shown in Figure 4, but also that the software can be tested early and be optimized. This includes not only the CNC and the PLC of the machine tool, but also the HMI, the coordinating control technology, as well as diagnostic, monitoring and process planning tools that use information on the machine tool. Fault or error conditions can be initiated via the virtual machine. They can be tested safely and without any risk. So the quality of the software can be improved as a whole, because, according to experts, approximately 80% of a PLC program serve only the error detection and the primary error response. Only 20% represent the functionality. The pure commissioning constitutes 15 to 25 % of the total processing time of the whole development process of a machine tool. A total of 90 % of the time are required for the commissioning of the electrical and control technology, of which 70 % is based on software errors. [8]

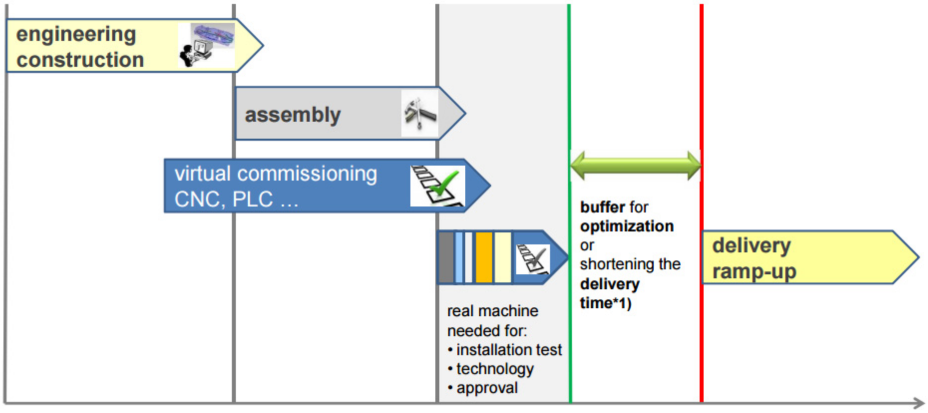

Figure 4: Development process of a machine tool using tools for virtual commissioning [6]

Further advantages which result by the use of software tools for virtual commissioning are according to [6]:

- up to 10% improved systemperformance by optimizing the timing sequences in the machine tool,
- up to 20% reduced product development costs and times by early product testing,
- up to 30% reduced project costs,
- up to 80% reduced commissioning time on the real machine tool.

Within the research project “CassaMobile”, an industrial control system of the type Beckhoff CX2040 with the control systemsoftware TwinCAT 3.1 (CNC and PLC) is used. The production module to be controlled is connected via EtherCAT fieldbus. As a framework for the selection of an appropriate simulation software for the virtual machine it was specified, that it should be oriented as close as possible to the real configuration. The original control system, as well as the original fieldbus – so a Hardware-in-the-Loop (HiL) simulation - should be used (see Figure 10). The virtual manufacturing units should be built together out of a modular construction kit, like the real mechatronic components. Considering these conditions, the software tool "ISG-virtuos", which is often used in engineering industry and whose foundations were created at ISW (Institute for Control Engineering of Machine Tools and Manufacturing Units, University of Stuttgart) [9].

This software tool differentiates between the behavior model and the graphical model of a machine. This separation is necessary because the behavior model has to provide deterministically the actual status of the production unit within the control system cycle time. This means, it has to react to control system command variables out of the CNC and the PLC within control systemreal-time. The graphical representation of the production unit can be calculated within a slower cycle time and without demand to determinism because the graphical representation mainly provides visual feedback to the operator of the virtual machine. The behavior model and the graphical model require additional data, which is not needed for the control system ramp up of the real production unit and therefore is not available.

To use the generator for configuration and parametrization of the control system, which was developed within the “CassaMobile” project, from the perspective of the control system the virtual production unit must be identically to the real production unit. With the schema in Figure 5 a corresponding reference structure was found. By a commissioning process, the selection of needed functional units takes place. They are taken as a machine unit (MU) out of a unit bearing to construct the machine tool. For the construction of the virtual machine, these functional units are available as virtual units (VU), which are a virtual image of the MUs, in a virtual machine database.

Both, for MU as for VU, CIMory provide all data needed for automatic control system generation. To set up the virtual machine, the CIMory of the VU has to be extended by a behavior (BU) and the graphic model (GU), which are not required for the MU.

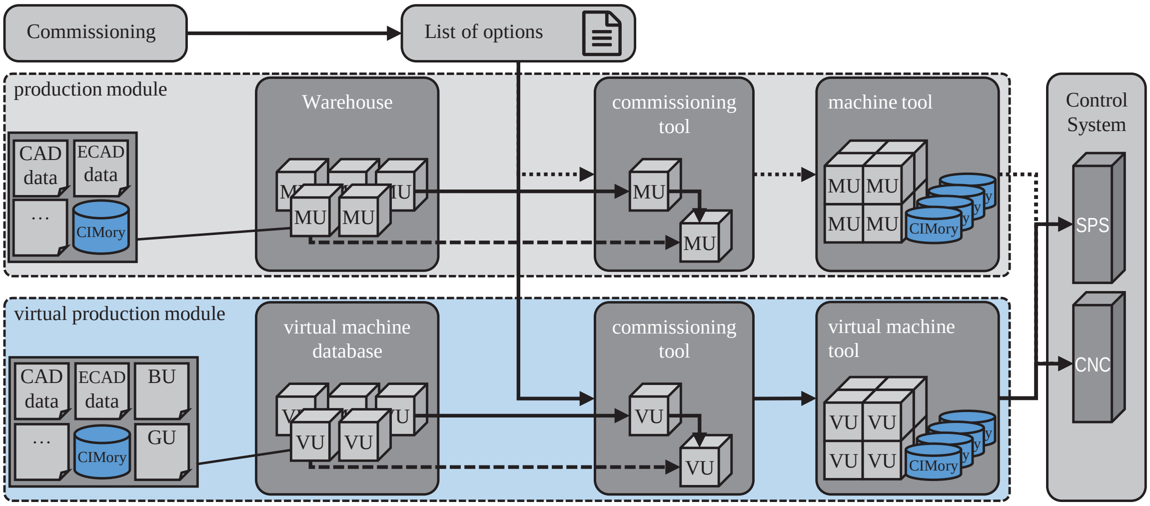

Figure 5: Reference structure for commissioning a real and a virtual machine tool

3. Automated configuration and parametrization of the CNC

A control system which can generate control data for a plurality of independently movable kinematics simultaneously is referred to as "multichannel". Each "CNC channel" is used to control a functional unit / machine tool. By PLC functions the program sequence of each channel is controlled and if necessary synchronized.

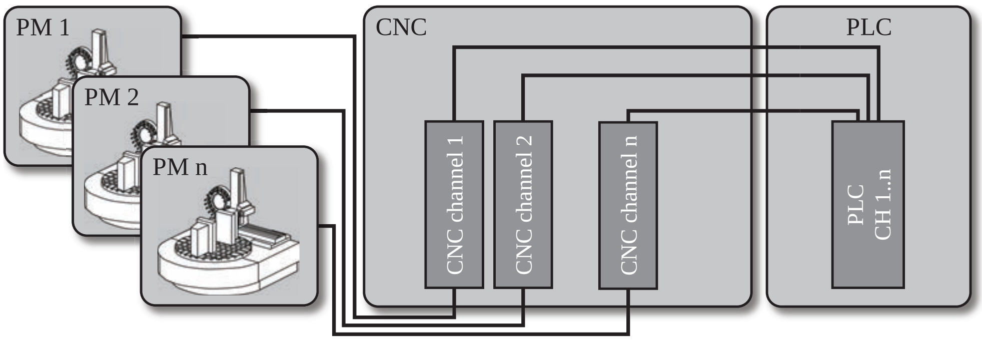

Figure 6: Assignment of CNC channels and PLC to production modules (PM)

To each CNC channel machine axes are assigned. E.g. for a 5-axis-machine, three linear and two rotational axes are assigned to the corresponding CNC channel. For each of these axes the CNC requires specific parameters that are merged together into a machine data set (MDS). Such are, for example, the maximum allowed speed, the maximum allowed acceleration, the position of the limit switches but also compensation values for spindle errors. Overall, these are usually several hundred data values, which are represented within the control system as “achsmds.lis” [10]. The assignment of the machine data set for the mechatronic component “axis” and thus for referencing within the CIMory would be a beneficial.

For their algorithms CNC channels require additional information, e.g. the path planning, interpolation and transformation. Within the used control system, such "channel data" is stored within files like the “sda.lis”, to name just the most important one. [10] These data describe control system technology relevant relationships between different MU, which cannot be described in a single component, but demand for machine specific additional information.

The VU used in the virtual machine are additionally described by behavior data and graphical data. The named software tool for building virtual machines offers the possibility to import such graphic data in the form of CAD data and to link them to each other via "docking elements" which have already been described in the CAD data. The 5-axis machine tool shown in Figure 7 is divided into the components "machine bed", "axis" and "spindle".

Each component has an origin coordinate system "DE0". Based on “DE0”, all further docking elements “DE1” … “DEn” are described with position and orientation. Axis can change the orientation (rotational axis) or the position (translational axis) of the subsequent docking element.

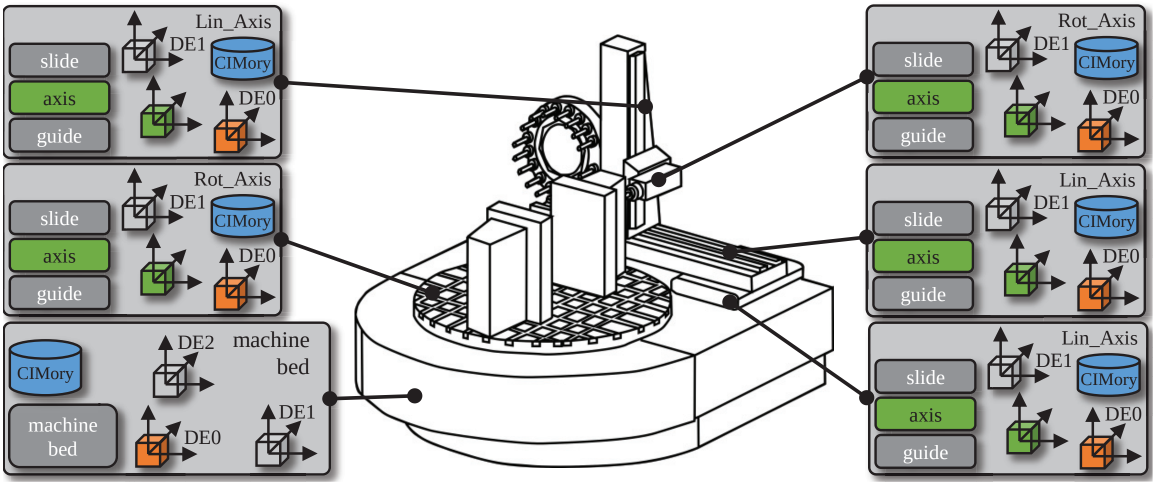

Figure 7: Mechatronic components of a 5-axis machine tool

CAD systems often use the so-called skeleton model to describe the relationship between the components. Such a skeleton model offers the possibility to consider and to design the individual mechatronic units for themselves. Each mechatronic unit contains docking elements to which subsequent mechatronic units can be attached. Normally, the machine bed is used as starting point, then the following mechatronic units are attached to it.

The subsequent mechatronic unit is attached to the main component with its “DE0”. The distance “v” between “DEn” and “DE0” is defined to “0”. In Figure 8, the skeleton chain for “machine bed”, “X-axis” and “Y-axis” of the 5-axis machine tool of Figure 7 is show.

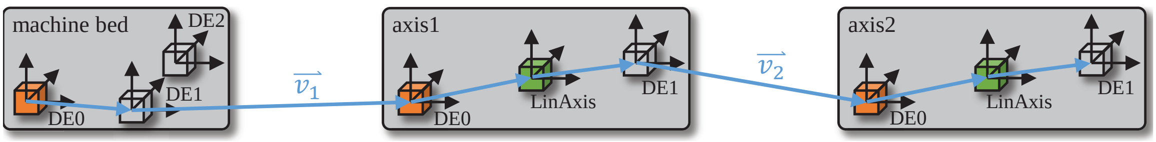

Figure 8: The skeleton model for connecting the mechatronic components

For the interconnection of the VU to a graphical presentation of the whole production unit, the interpretation of the skeleton model offers itself. As the graphical representation of the total kinematic can be derived from this model, the corresponding part of the CNC channel data may be derived from it within the automated control system generation.

To do an automatic recognition of the relationships between the mechatronic units via the fieldbus, a virtual VU "KINEMATIK" was established. The assigned CIMory contains the exact data of the skeleton model.

Other important CNC channel data describes the availability of so-called machine functions (M functions) in the control system channel. In addition to standardized functions like "M30" for "end of program", which are done by the control system function itself, other functions are to be determined within the NC control data ("CNC program"), which trigger corresponding functionalities. This is done by PLC inputs and outputs like shown in Figure 9. There, a behavioral model of a machine function is shown (BU), which has the necessary communication inputs (green) and the necessary communication outputs (blue). The CIMory contains data describing the M functions, which are required or provided by the machine component, e.g. M4801 (activation of the function) and M4802 (deactivation of the function). The generator for configuration and parametrization of the control system reads out this function description and makes it available in the CNC channel. It also sets the corresponding logic of the machine function (MF48) in the PLC, which is activated by M4801 and disabled by M4802. The BU is programmed so that it responds to the machine function MF48 of the PLC and responds with matching values.

The part of the channel data, describing the machine functions, is derivable this way out of the CIMory of the controlled machine function. With this information, the channel data is extended.

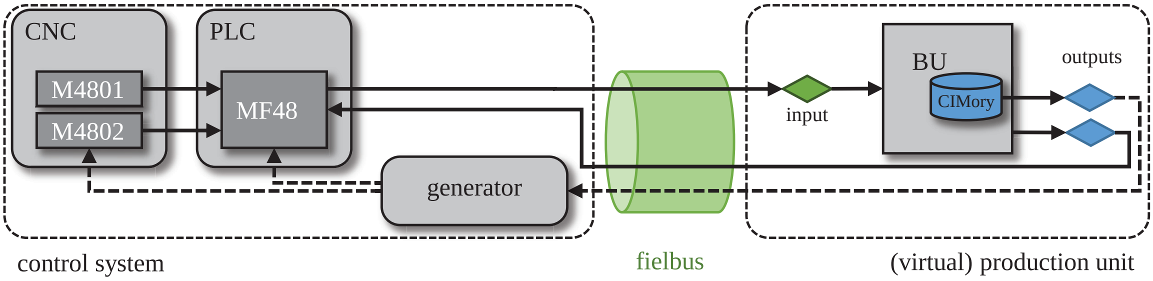

Figure 9: Mechatronic unit with behaviour model

4. Realization

For the research project "CassaMobile" the production unit "5-Axis Milling Module" was built as virtual machine in parallel to the real machine. Even before completion of the real production unit, it was possible to ramp up the control system on the virtual production unit. The virtual production unit served the project partners to test and to develop their software tools for planning, monitoring and HMI. By copying the virtual machine to multiple workstations the availability of a testing production unit could be increased and a parallel development and testing of various software packages could be made possible this way.

As the virtual production unit was created, the same modularization of both, the graphical and the behavior model were created with the same modularization as the real production unit. Doing so, it was possible without adaptation to control both the virtual and the real production unit with one and the same control system (see Figure 10).

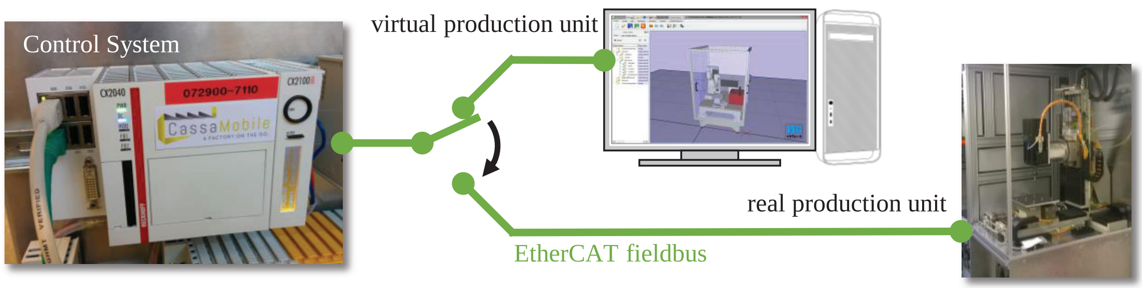

Figure 10: HiL-Simulation for the production module "5-axis-milling-module" of „CassaMobile"

5. Conclusion

By CIMory (Configuration and Information Memory) it is possible to store data for and within a specific mechatronic component. This data can be used for the automated generation of a control system (CNC and PLC), as implemented for the project "CassaMobile". Within this article, it is described how the CIMory can be used for virtual machines as well. For this, the CIMory has been extended by a behavior model (BU) and a graphic model (GU) of the mechatronic component. These can now be used by the generator for configuration and parametrization of the control system. In addition, it is possible to get further information from the data of the virtual machine, which makes it possible to completely automate the configuration and parametrization of the control system.

Acknowledgement

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